An Overview of the University of Toronto Glacial Systems Model (UofT GSM)

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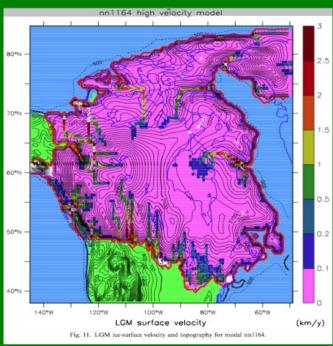
Future Projects



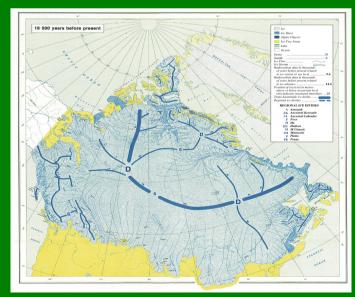
Introduction

University of Toronto Glacial Systems Model (UofT GSM)

- models ice sheet coverage under climate conditions (e.g North America at Last Glacial Maximum (LGM))
- reproduced triple dome structure of Laurentide Ice Sheet, predicted by Dyke and Prest in 1987
- surface drainage component added to determine drainage of Laurentide ice sheet (Tarasov & Peltier 2006)



Tarasov & Peltier 2004



Dyke & Prest 1987

Uof T GSM solves the thickness distribution of an ice sheet wrt time

Continuity Equation

$$\left| \frac{\partial H}{\partial t} = -\nabla_h \cdot \int \frac{h}{z_b} \vec{V}(z) dz + G(\vec{r}, T) \right|$$

Shallow-ice approximation in velocity calculation

- neglect horizontal gradients of stresses wrt vertical

Inappropriate when

- base topography varies quickly wrt ice thickness
- in regions with strong horizontal shear (e.g. ice streams)
- in regions with strong longitudinal stresses (e.g. grounding line, see Schoof 2007)

Ice Dynamics

UofT GSM

Glen's Flow Law (n=3) & strain rate factor A(T)

- age factor partly compensates for anisotropy of ice (hardening & softening)

$$A(T) = f(age)Be^{-Q/(R_{gas}T')}$$

Conservation of energy

- change in local temperature due to
 - vertical heat diffusion
 - 3D advection
 - deformational heating

$$\rho_{i}c_{i}(T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left\{k_{i}(T)\frac{dT}{dz}\right\} - \rho_{i}c_{i}(T)\vec{V}\cdot\nabla T + Q_{d}$$

- lower boundary conditions includes heat from
 - basal sliding
 - geothermal sources
- upper boundary includes surface temperature and precipitation
 Tarasov & Peltier 2002, 2007

Basal Dynamics

UofT GSM

Basal slip and till deformation mechanisms of basal velocity

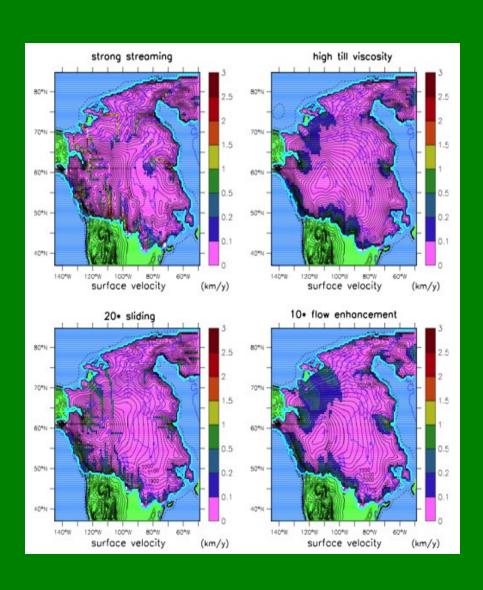
- initiate at 0.25°C below pressure melting point temperature

Basal slip

-Weertman sliding law with exponent of 3

Till deformation

- assume till is Coulomb plastic at yield stress (deformation only occurs when yield stress reached)
- strain rate equations depend on stress and other factors
- till viscosity, μ_0 , determined in optimisation process



Basal Dynamics

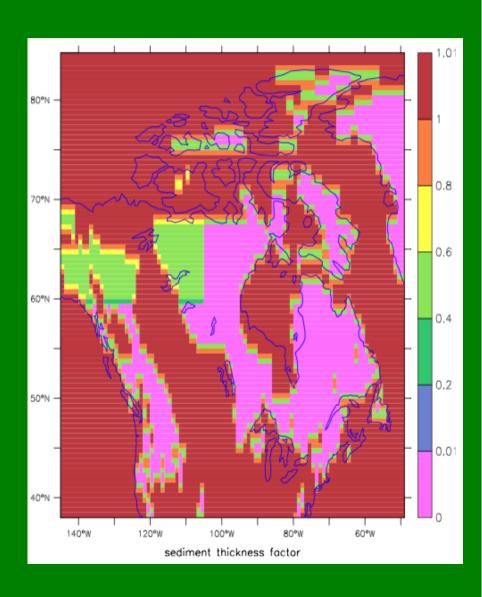
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$$U(z_b) = \frac{f_b(x, y)}{n+1} \tau^{n+1} \frac{\mu_0^{-n}}{(\rho_t - \rho_w) gtan\phi} (2D_0)^{1-n}$$

Constants

Till Deformation

- n, ϕ , D_0 , ρ_t from Jenson et al 1996
- Till factor $f_b(x,y)$ derived from published sediment thickness measurements (Laske and Masters 1997)
- normalised to 1 for till depths >20m
- other depths expressed as fraction of 20m
- set to 0 for values of f_b(x,y)<0.6
 (limit from fits to constraints)



Mass Balance

UofT GSM

Surface Accumulation

- precipitation map interpolated between LGM and present-day GCM climate field simulations using glacial index inferred from (Paleoclimate Modelling Intercomparison Project) PMIP simulations

Surface Ablation

- Positive Degree Day (PDD) method with coefficients dependent on mean summer temperatures
- refreezing calculation

Base Ablation

- basal slip melting calculated as part of basal sliding component
- when slip heat exceeds pressure melting point, produces meltwater

Vertical heat diffusion through bedrock

- calculated to 3 km depth
- using geothermal heat flux map from Pollack et al (1993) as lower boundary condition

 Tarasov & Peltier 2002, 2007

Ice Shelf/Calving

UofT GSM

No explicit ice shelf calculation

Flotation criterion used to determine when ice sheet sufficiently buoyant to calve

Calving occurs in one of two circumstances:

- grid cell water depth exceeds arbitrary critical value

OR

- sea-ice blocking conditions



Sea-ice blocking conditions

- mean summer sea-surface temp > critical value
- grid cell ice thickness < 1.1*maximum buoyant thickness
- adjacent ice-free grid cell with water depth >30m
- ice-free regional drainage outlet

Calving velocity

$$U_{c} = U_{c_{max}} n_{edge} min \left\{ 1, \left(\frac{1.1 H_{flot} - H}{0.25 H_{flot}} \right)^{2} \right\} \left\{ \frac{e^{\left(\frac{T_{s} - T_{c_{max}}}{T_{c_{max}} - T_{c_{min}}} \right)} - e^{-1}}{1 - e^{-1}} \right\}$$

Bedrock Topography

UofT GSM

Bedrock response to ice sheet

- convolve (space & time) surface load per unit area with radial-displacement Green's function

Use VM2 (Peltier 1996) for deep, radial viscosity profile and PREM (Dziewonski & Anderson 1981) for deep, elastic structure in mantle

Solve spectrally with truncation at order 256

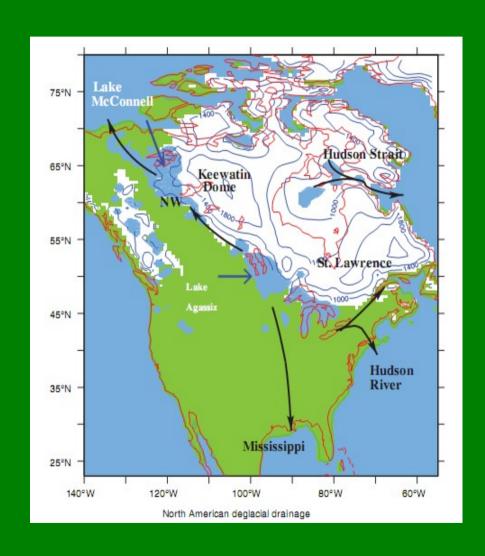
Time step = 100 years, run asynchronously with dynamic model

Tarasov & Peltier (2006) used surface drainage calculation to determine discharge location at start of Younger Dryas

Diagnostic calculation that performs two iterations for each step

1st iteration:

- defines pointers for each grid cell in direction of nearest down-slope inland lakes or deep-water outlets
- calculates maximum water levels for inland catchments



Surface Drainage

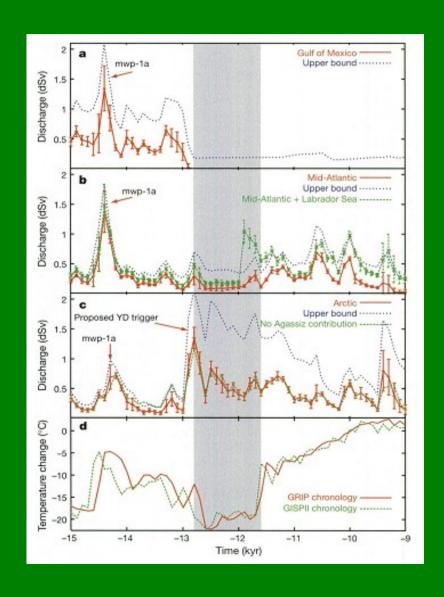
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2nd iteration:

- repeats pointer calculation, considering how full lake is from previous time step and this one
- updates pointers as catchments fill
- total meltwater into ocean summed from amount draining into deep-water outlets

Neglects

- surface erosion
- groundwater absorption
- geoid perturbations



Calculates drainage only from surface of ice sheet (or ice-free land)

- ice surface heights determined in ice sheet calculation
- for ice-free regions, adapt versions of US Geological Survey digital elevation model and National Geophysical Data Centre bathymetry map

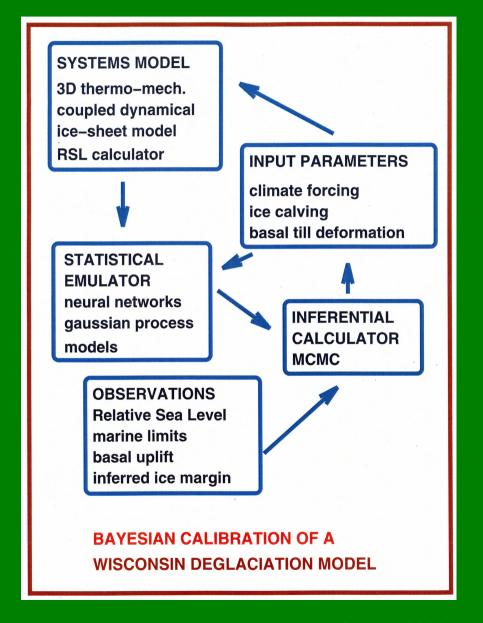
Parameter Optimisation

Choose 22 relatively unconstrained parameters of model to optimise using Bayesian technique

- till viscosity, 3 calving parameters, 2 Heinrich event parameters and 16 climate forcing parameters

Define probable range for each parameter

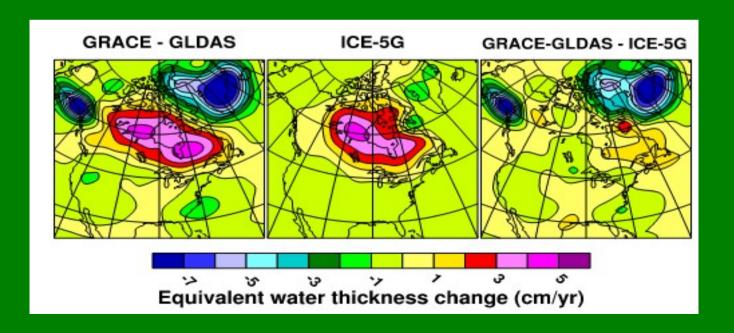
Run ensemble of simulations with parameter values selected randomly within ranges



Parameter Optimisation

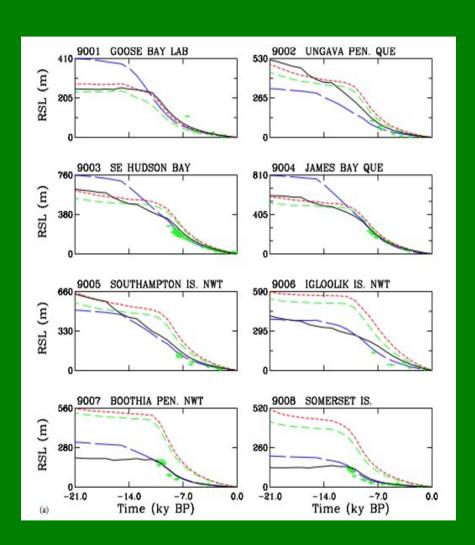
Train neural network on relative sea level histories derived from these ensemble results

Constrain with relative sea level histories calculated using a geophysical ice model (ICE-4G or ICE-5G) and geodetic predictions (GRACE)



Parameter Optimisation

Optimal parameter choice minimises difference between two sets of predictions, and method gives estimate of parameter uncertainty



Future Work

Couple UofT GSM to CCSM4

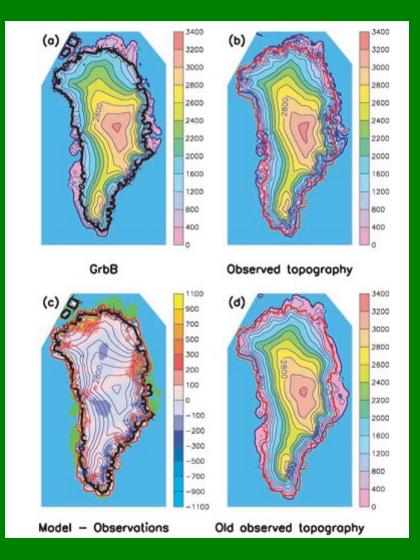
- reduce uncertainties in climate forcing parameters
- model feedback between changing climate and Greenland ice sheet

Include hydrology scheme in thermomechanical model

- include effects of groundwater take-up of meltwater (Lemieux 2008)

Introduce triangular unstructured grid numerical scheme to describe ice dynamics processes (Stuhne & Peltier 2006)

 use adaptive spacing for high-shear areas



Tarasov & Peltier 2002